Selection of real-life analogues for future lakes and mires at a repository site

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Abstract. In Finland, Olkiluoto Island on the western coast has been selected as a repository site for spent nuclear fuel. Due to the shallow sea areas around the island, the postglacial land uplift is going to change the landscape within the next millennia. For instance, new lake ecosystems are going to develop, part of them further developing into mires. Primary mire formation, with new mires developing directly on the emerging land, will also occur. Concerning radionuclide transport models, the properties of the future ecosystems surrounding Olkiluoto Island can be forecast based on the properties of present lakes and mires. Due to the lack of site-specific data, lakes and mires of various successional stages were selected within a larger geographical area as analogues of the future ones. Here we present an example of a systematic process for selection of appropriate analogue sites.

1. INTRODUCTION

1.1 Background

Posiva Oy is responsible for implementing a repository programme for spent nuclear fuel from the Finnish nuclear power reactors currently in operation and under construction. The spent nuclear fuel is planned to be disposed of in a repository located on Olkiluoto Island, which is situated in the municipality of Eurajoki on the Finnish coast of the Baltic Sea. To address the long term safety requirements, Posiva Oy is compiling a Safety Case Portfolio, which was introduced in the Safety Case Plan of 2004 [1], revised in 2008 [2]. Comprehensive studies concerning the characteristics of the site have been going on since 2002. One factor to be taken into account in the safety analyses is the postglacial land uplift (approximately 6–6.8 mm/y [3,4]), which affects the hydrogeochemical and biological systems of Olkiluoto and its surroundings. Due to the shallow sea areas around Olkiluoto Island, this phenomenon is going to greatly change the landscape within the next millennia. For instance, new lake ecosystems are going to develop (Fig. 1), part of them further developing into

mires. Primary mire formation, with new mires developing directly on the emerging land, will also occur under certain conditions.

The properties of the future lake and mire ecosystems surrounding Olkiluoto Island can be forecast and radionuclide transport models applied based on the properties of present lakes and mires. Currently, however, there are no lakes and only a few mires on the island. The existing mires are small and young, and thus give only a weak basis for the forecasts of future landscapes.

Due to the lack of site-specific data in the long-term context, a project was initiated, where lakes and mires of various successional stages were selected within a larger geographical area as analogues of those expected to form at the Olkiluoto site. An intersection of good analogue sites and those with plenty of study results was searched for. The project and detailed results have been presented by Haapanen et al. [5], and here the systematic process for selection of analogue sites, appropriate to the multi-millennial site-specific assessment context, is illustrated.

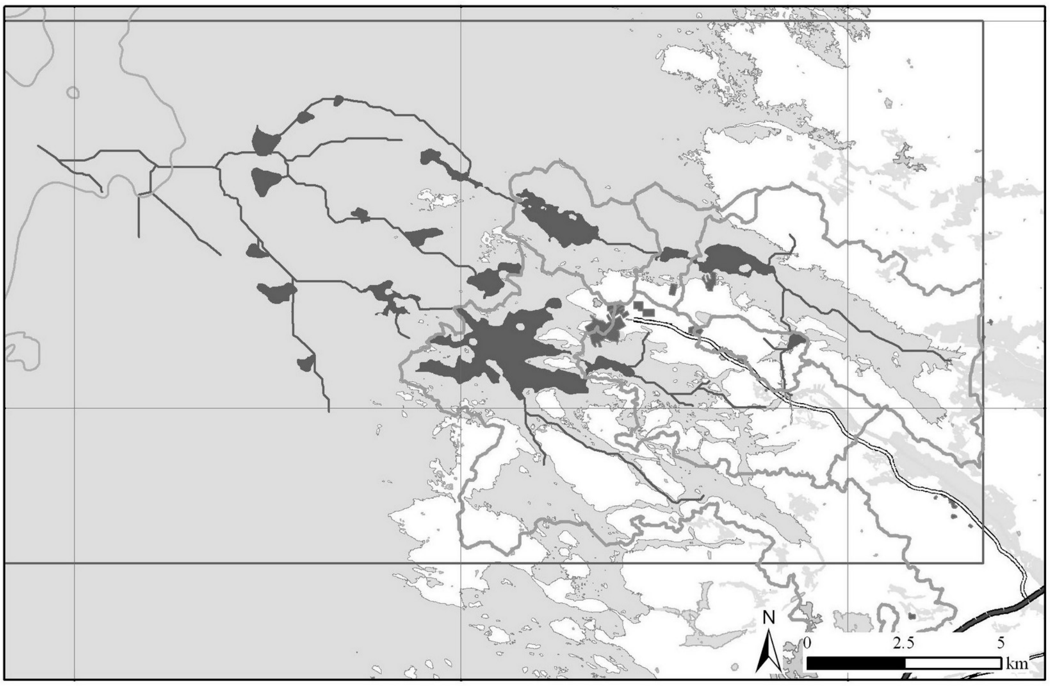

Figure 1. Main future lakes and their catchment areas developing within some millennia in the present sea areas around the Olkiluoto repository site [6]. Background map: topographic database by the National Land Survey of Finland, derivation of catchments based on these data, as well. Map layout by Jani Helin/Posiva Oy.

1.2 Succession of lakes on Finnish land uplift coast

The geological development of all modern lakes in Finland began after the last – Weichselian – glaciation. The Baltic Sea experienced rapid and extreme changes when the Scandinavian ice sheet retreated. In the submerged coastal areas, lake basins were isolated from the various stages of the Baltic Sea as a result of isostatic uplift and tilting of the land. This crustal process is still continuing and thus new lakes are developing from bays along the Finnish coast via land uplift driven isolation.

The development of lakes does not end at the isolation. The development is determined by the bedrock, soil, climate and the vegetation cover of the surrounding areas. Almost all of the lakes in the submerged areas have started as eutrophic ones after the sea has retreated. There was a flux of nutrients from the so far unleached mineral soils to the lakes. The trend is towards oligotrophy due to bedrock, soil and climatic properties. Exceptions are thick clay areas rich with nutrients: there the nutrient situation of lakes is generally good [7-8].

In addition to the changes in chemical and biological conditions, the inflow and outflow channels erode and in-flowing sediments make the pools shallower. Into many Finnish lake bottoms, a 2–4 m deep gyttja/mud layer has been accumulated after the glaciation [7]. With increasing aquatic vegetation the overgrowing of lakes goes on and the lakes develop towards mires.

1.3 Succession of mires on Finnish land uplift coast

Primary mire formation is a process in which the fresh soil surface is occupied directly by mire vegetation after emergence from water. Requirements include poorly permeable land with flat topography or small depressions. Due to the continuing land uplift, the properties of coastal mires change for several millennia, during which the climate, topography, moisture conditions and soil nutrients regulate the development. In general, the coastal meadows transfer into treeless fens, fens with deciduous trees or spruce mires. These in turn are replaced with white moss-dominated pine bogs when the influence of surface and ground water decreases. At an elevation of approx. 10–20 metres above sea level (after 1,500–3,500 years of succession), a thicker bed of white moss starts to accumulate, disconnecting the mire surface from groundwater, resulting in concentric bogs with hummocks and hollows. The centres of mires become again treeless or near treeless [9-12].

Terrestrialization means a hydroseral succession from open water basin to mire and is another way of coastal mire formation. It may also occur later as explained in Section 1.2.

Also forests may be converted into mires via paludification. This occurs mainly in places where topography directs enough runoff to create waterlogged conditions. On poorly permeable lands, surface waters may fill depressions, after which white mosses invade the spots. Other factors promoting paludification include forest fires, storm damages and wide clear cuttings. On well permeable lands, a rise in groundwater level is needed [11]. Mires may also expand to nearby forest areas via lateral growth. This expansion is mostly regulated by topography [13].

2. MATERIAL AND METHODS

The selected analogue sites should be as similar as possible to the sites which will develop in the future at Olkiluoto area. Geological, biological and climatic properties and their historical development limited the search area into Southwestern Finland. Within the defined search area, the following parameters were considered most important:

- Size and shape (in case of mires these may be altered during time due to peat accumulation and mire expansion)
- Size and soil properties of the catchment area
- Degree of human impact
- Nutrient level of water or peat
- Distance from coastline
- For lakes: drainage type (drainage lake/headwater lake/closed lake)
- For mires: origin (primary mire formation, lake terrestrialization, paludification of mineral soils)

Some of these properties could be estimated via GIS analyses carried out by Ikonen et al. [6,14]. The lakes predicted to develop in the nearby areas of Olkiluoto Island are a lake chain, a small lake and an overgrown lake, all very shallow (mean depth ca. 1–5 m) already at the beginning, with areas between 10 and 800 ha.

Predicting future mire properties is even more demanding than lakes, since, in addition to topographic and edaphic factors, climate plays a large role in the development of a mire, from initiation to the later development stages. As seen in Section 1.3, three ways of initiation exist, and afterwards, the mire may

expand into surrounding forest areas. According to GIS analyses by Ikonen et al. [14], the future mires would originally cover small areas and situate mainly on till soils and clays. A large variation of shapes is to be expected. It was decided to go for a very young mire, a young mire, an old and small mire and an old and large mire in the search of analogues.

Data sources outside Olkiluoto included literature, environmental databases and generic GIS data. Major GIS data providers in Finland from the point of view of this study are:

- Geological Survey of Finland
- National Land Survey
- Finnish Environmental Administration
- Finnish Forest Research Institute
- MTT Agrifood Research Finland
- Finnish Meteorological Institute
- Finnish Game and Fisheries Research Institute.

Several licences were acquired for GIS data and databases, to be used also in other studies in the repository programme. Some data were used at the metadata-level only in the selection process.

The selection process for lakes went as follows:

1. A set of most relevant lakes (ca. 100) was selected based on expert knowledge.
2. Parameter list was completed using databases and literature. Part of the data remained at metadata-level.
3. The pre-selected lakes were extracted from the topographic database of National Land Survey of Finland and their locations and shapes were studied on printed A0 maps. A sub-set was selected based on the lake properties.
4. The list was further fine-tuned; some lakes were added and some removed, after more information was collected concerning available data.

The selection process for mires went as follows:

1. Study locations found in literature were converted into GIS format. Concerning parameters, work was mainly carried out at metadata-level, since mires typically comprise of sub-areas with varying properties.
2. After browsing the data sources, it was decided that research carried out under the mire surface (profiles, chemical and physical properties) should be emphasized, since the vegetation types and growing stock volumes can be inventoried beforehand.
3. Sites with most important data sources (determined in step 2) were selected and their locations plotted in GIS over various thematic backgrounds (topography, soils).
4. After preliminary selection, some mires with poorer data situation were added to balance the regional coverage.

Generalization of the whole process is presented in Fig. 2. In the process, 27 lakes and 33 mires were selected. The characteristics of these objects were presented in a standardized format and literature lists were completed.

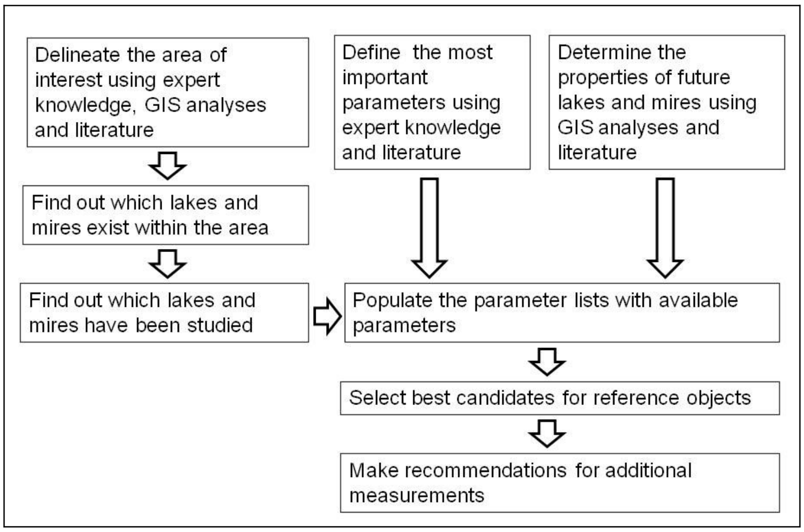

Figure 2. Steps taken in the process of selecting real-life analogues for future lakes and mires in the Olkiluoto repository area.

3. RESULTS AND DISCUSSION

Of the described 27 lakes and 33 mires, a smaller sub-set of 11 lakes and 11 mires was selected for a closer look: catchments were calculated and maps showing their extent, the extent of the watershed, the surrounding topography, soil types and major landscape elements were drawn. Finally, 7 lakes and 4 mires were presented in the Olkiluoto Biosphere Description 2009 [15]. Some data studied at the metadata-level were acquired for the selected final analogue sites.

During the review and selection process, it was confirmed that the following issues cause uncertainty in the applicability of the information on analogue sites:

- Human actions have changed majority of the lakes and mires in Southwestern Finland.
- The properties of future lakes and mires nearby Olkiluoto are based on GIS analyses with partly inaccurate data and many assumptions, e.g. climate change may change the picture.
- Any object cannot be an exact analogue to another, even less to a ecosystem object predicted to form long in the future; a multitude of factors affect to the state of the objects and usually only a rather limited set of parameters have been studied together.
- Lakes with most data are typically large lakes or lakes that have had problems in their condition. Similarly, small mires have not been studied in the economically focused peat surveys. Thus the selection among small-sized lakes and mires was very random.
- Parameters available for lakes and mires depend on the emphasis of the studies carried out on them. Further, the monitoring periods vary from single survey to long-term studies, and the spatial sampling densities from one survey point to a dense grid of measurements.
- Availability and organization of information differed between lakes and mires, and the situation was better in the case of lakes due to a greater amount of uses (water reservoirs, hydropower, irrigation, fishing, recreation and flood control) and larger public interest.
- The administrational borders are problematic when compiling data over a large area. Moreover, changes in these borders make comparisons over time very difficult.
- Preparation of mire data for GIS analyses was laborious due to differing naming conventions, inaccurate locations, similar mire names occurring in several municipalities etc.

4. CONCLUSIONS

At Olkiluoto, the post-glacial land uplift changes the landscape from a coastal island to an inland site within some millennia - i.e. by the time the earliest releases are expected to be able to reach the biosphere from the repository deep in the crystalline bedrock. New lakes and mires will form in the present offshore area. Despite the lack of lakes and well-developed mires at present Olkiluoto Island, input data appropriate to the site-specific context is required for the repository licensing assessments. Therefore, we set out for finding analogue objects in a larger geographical area.

Even though no analogue can ever be perfect, this is a more reasonable approach compared with constructing arbitrary sets of (possibly internally inconsistent) parameter values for the models. Concerning the need of specific

parameters, there is now a possibility to complement the parameter sets with new studies targeted on the analogue sites. In this sense, aerial photographs have been taken, and supplementary field inventories, GIS analyses, and collection and analyses of flora, fauna and soil/peat samples have been carried out. Interdisciplinary interpretation of the collected data is going on.

Another implication to the biosphere assessment is that of increasing the knowledge on human actions, which in Finland have had an important role in modifying the conditions of lakes and mires. Based on the collected data, formulation of scenarios concerning future human actions is on a sounder basis.

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